Prediction and Assimilation Challenges for Hydrometeorological Operational Applications: An NCEP Perspective

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Workshop on Satellite Observations
of the Global Water Cycle
March 7, 2007
Irvine, CA

"Where America's Climate, Weather and Ocean Services Begin"

Outline

- NCEP's role in the seamless suite of climate/weather/water prediction
- Recent results
- Model challenges in the weather climate linkage
  - Focus on the land model
- Ongoing data assimilation challenges
  - The role of the NASA/NOAA/DoD JCSDA
- Summary/Issues

The Path to NOAA's Seamless Suite of Products and Prediction Services

Observe

- Process
- Assimilate
- Predict

NCEP

Products & Forecast Services

Central Guidance

WFOs RFCs

IBM Supercomputer at Gaithersburg, MD Computer Center

Distribute

Respond & Feedback

To Serve Diverse Customer Base

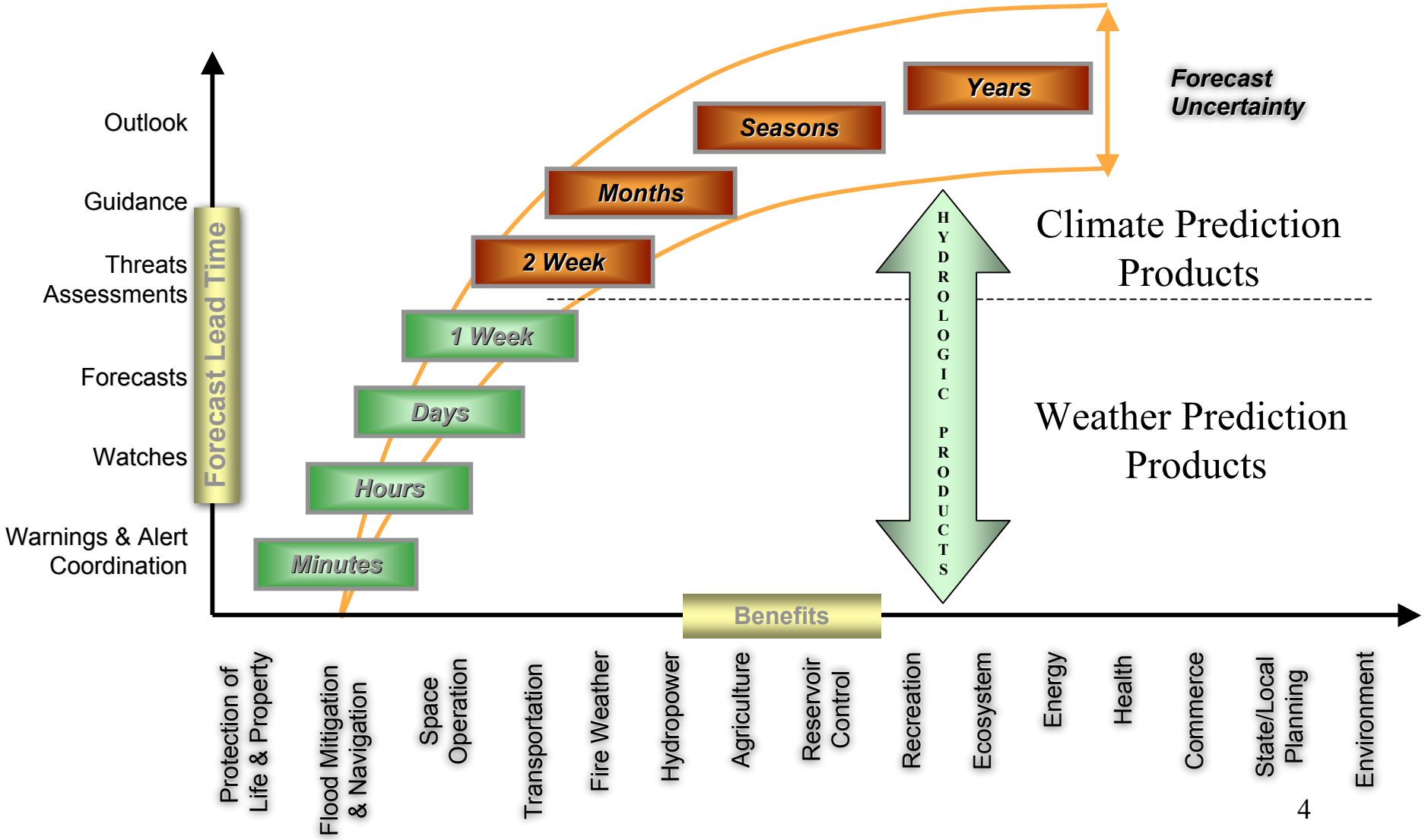
e.g., National Association of State Energy Officials, Emergency Managers, Water Resource Agencies, …

Research, Development and Technology Infusion

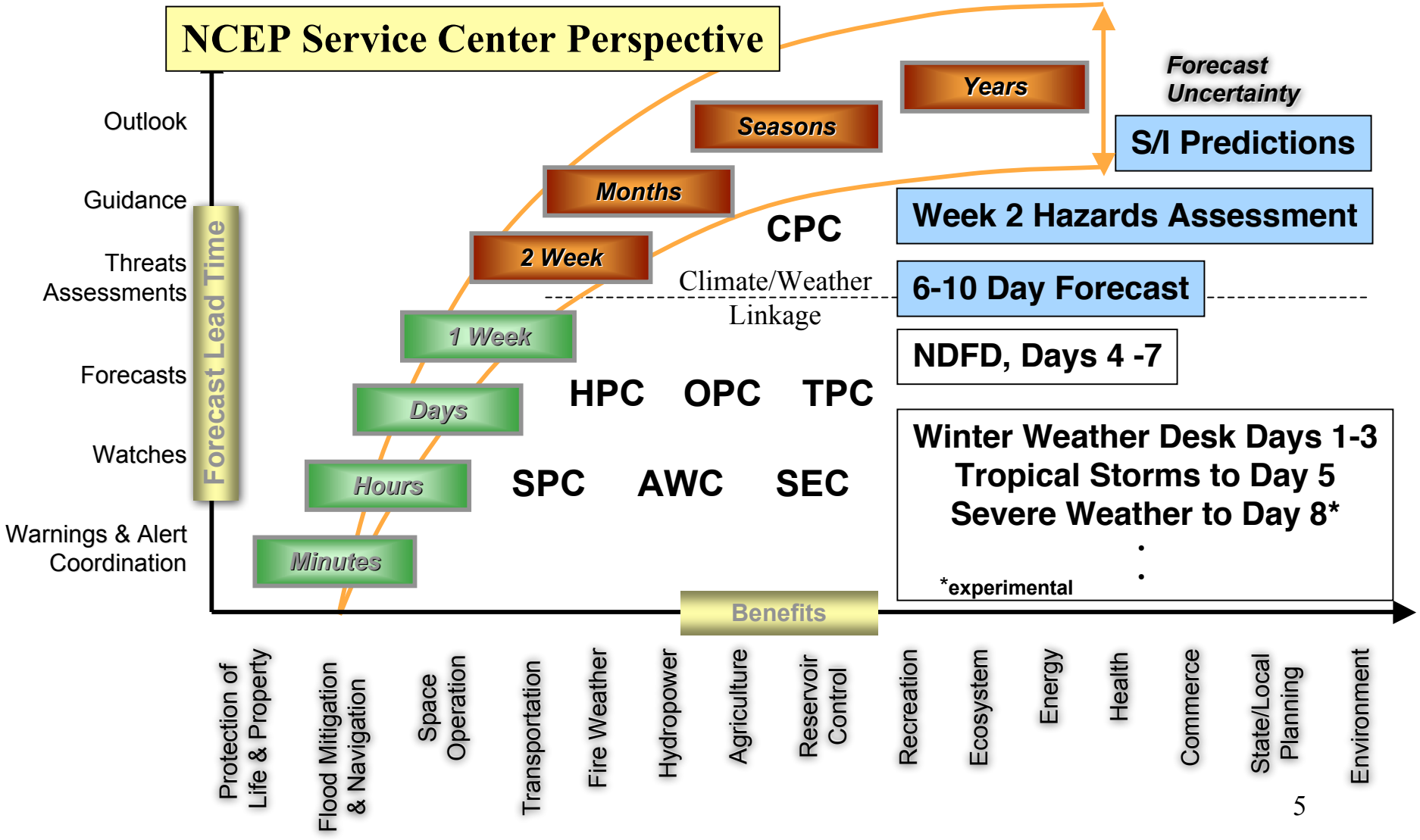
Feedback

Prediction is now inherently linked to numerical models

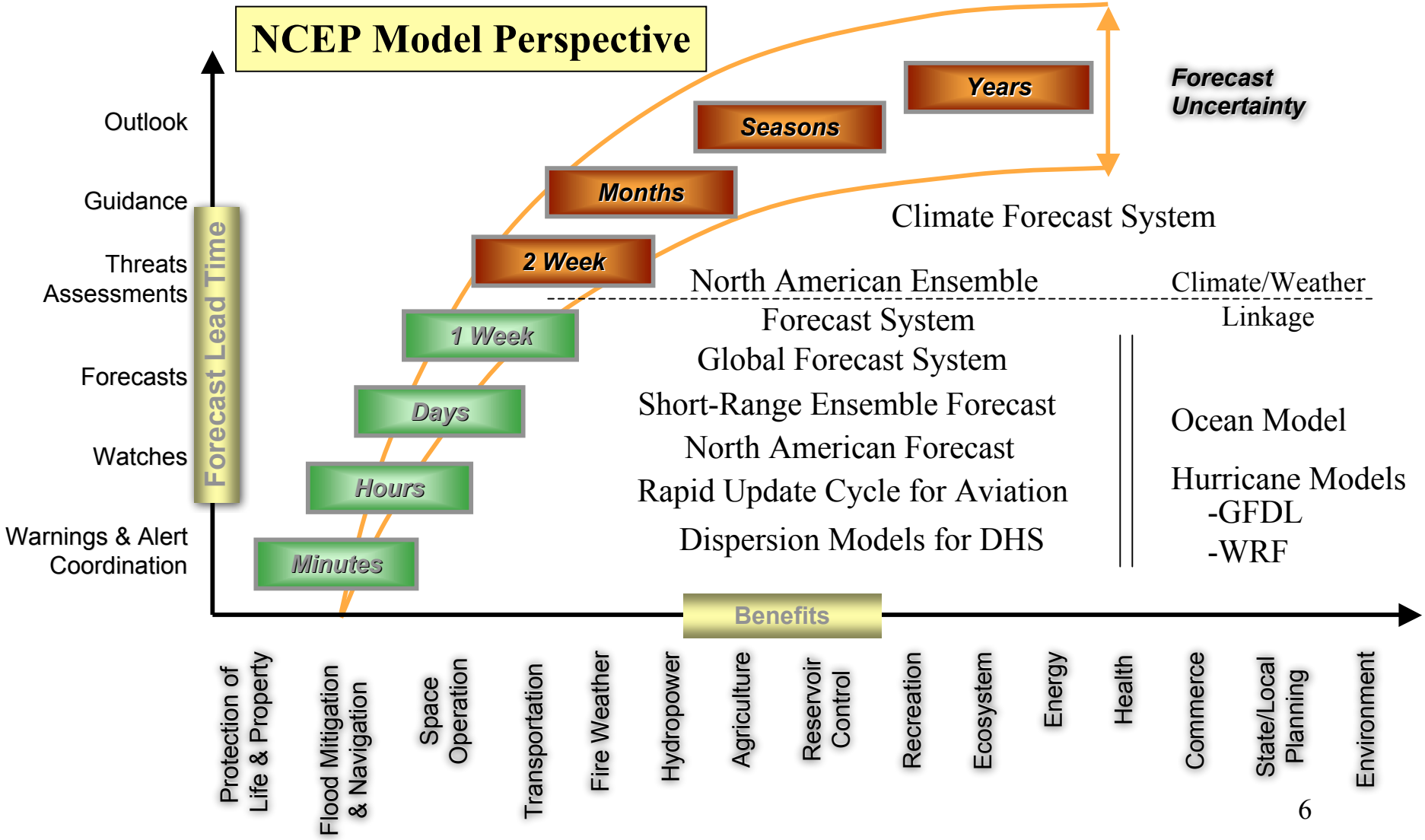
NOAA Seamless Suite of Forecast Products Spanning Climate/Weather/Water



NOAA Seamless Suite of Forecast Products Spanning Climate and Weather



NOAA Seamless Suite of Forecast Products Spanning Climate and Weather



Computing Capability

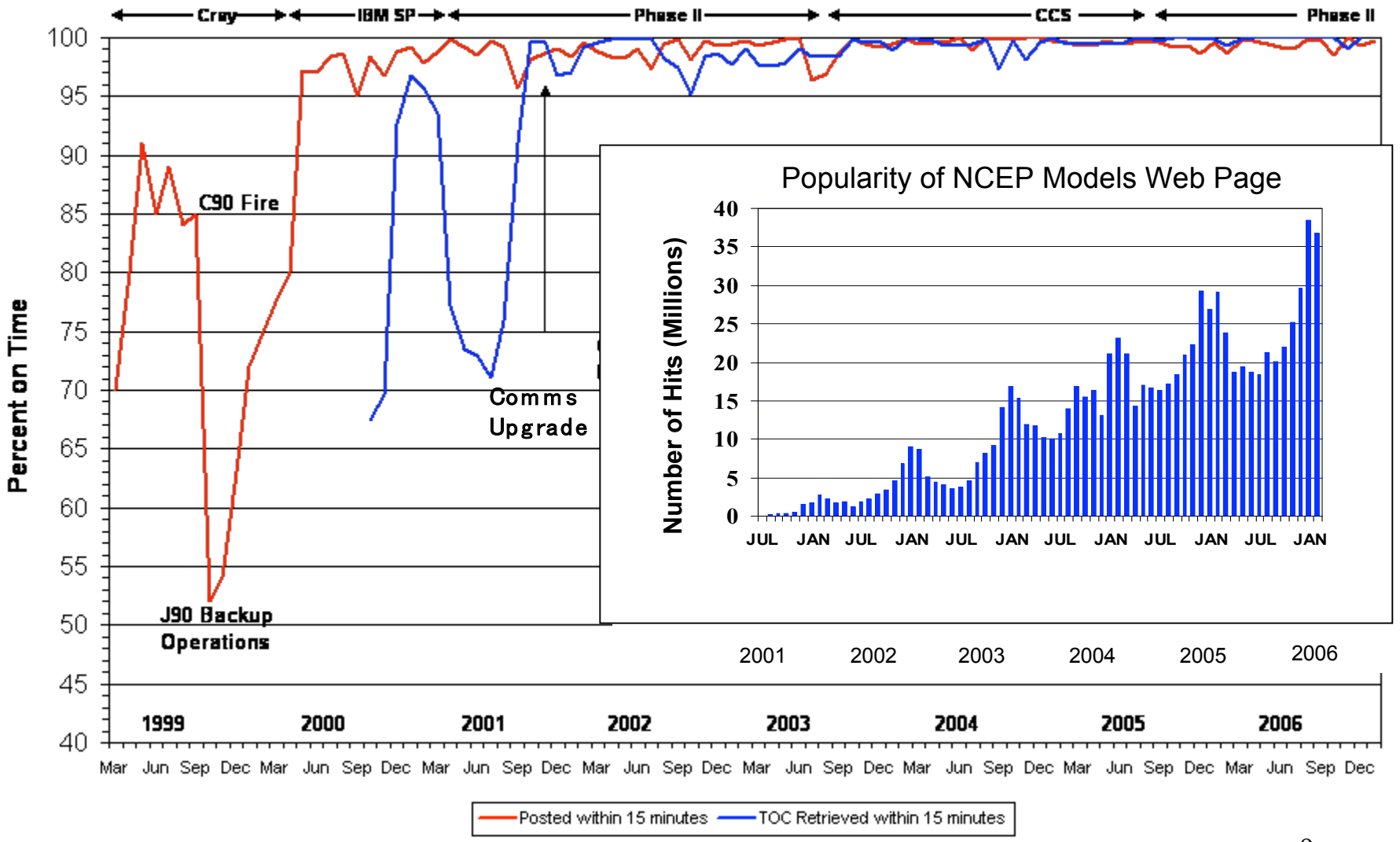
Primary Weather	**$13.9 M**
Primary Climate	**$5.3 M**
Backup	**$7.2 M**
Total:	**$26.4 M**

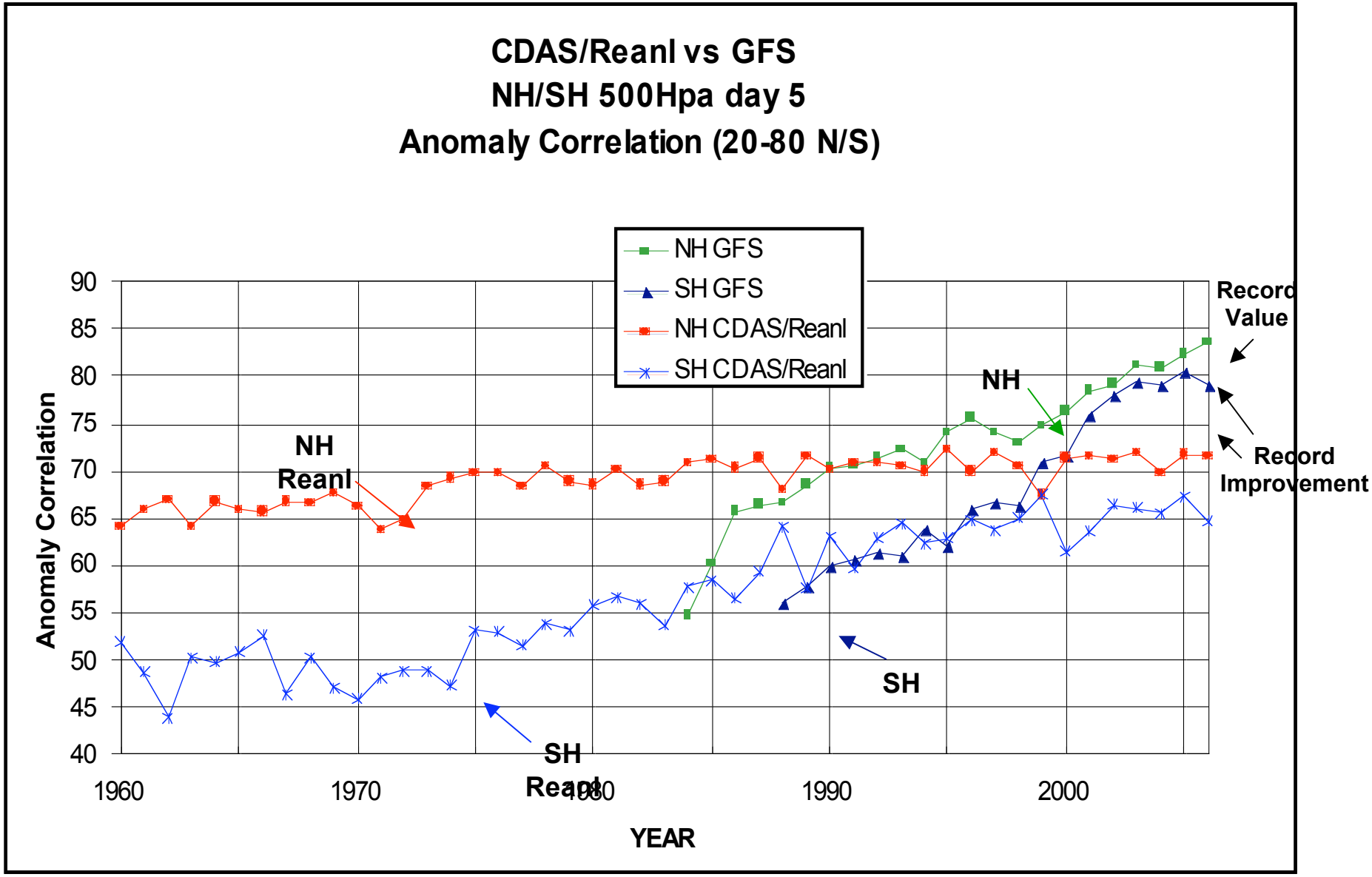
Commissioned/Operational IBM Supercomputer in Gaithersburg, MD (June 6, 2003)

- Receives Over 239 Million Global Observations Daily
- Computational Speed: 13.99 Trillion Calculations/Sec
- Generates More Than 14.8 Million Model Fields Each Day
  - 6 million of which are derived from the global ensemble
- Global Models (Weather, Ocean, Climate)
- Regional Models (Aviation, Severe Weather, Fire Weather)
- Hazards Models (Hurricane, Volcanic Ash, Dispersion)
- Backup located in Fairmont, WV
- Upgrade Operational January 24, 2007

Recent Results

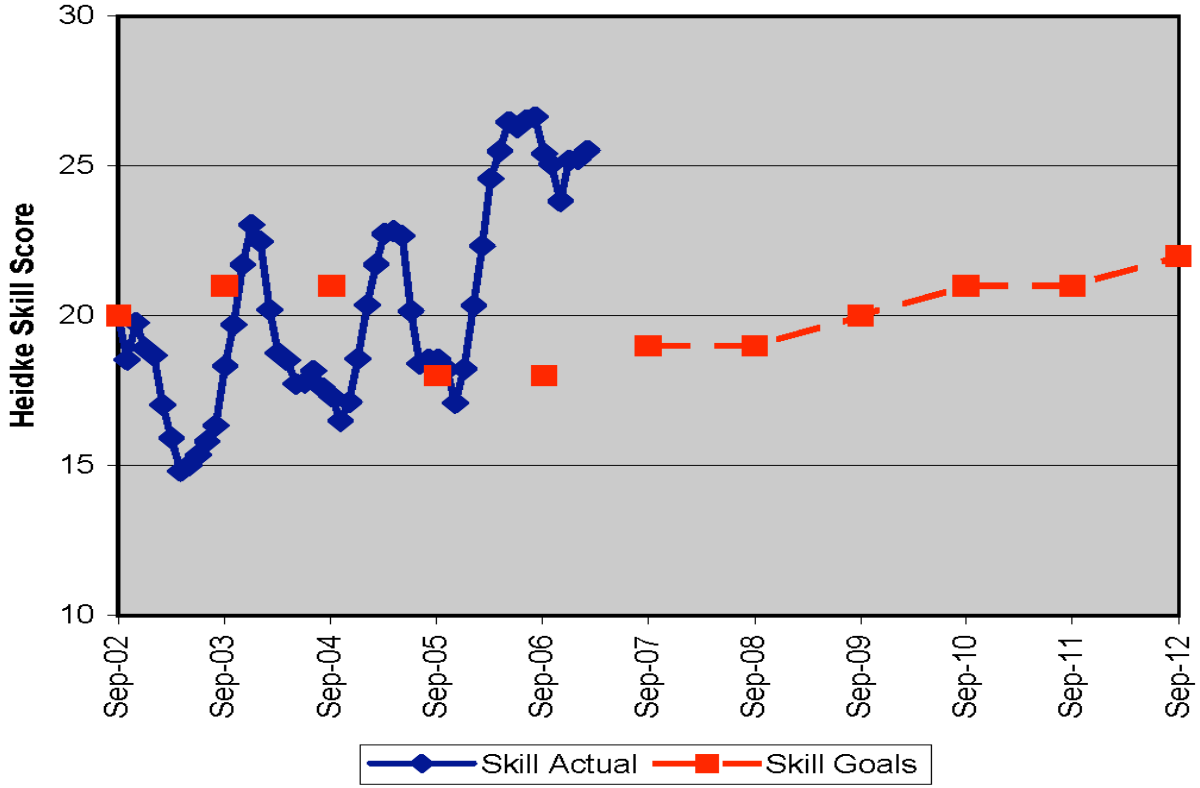
Product Generation Summary



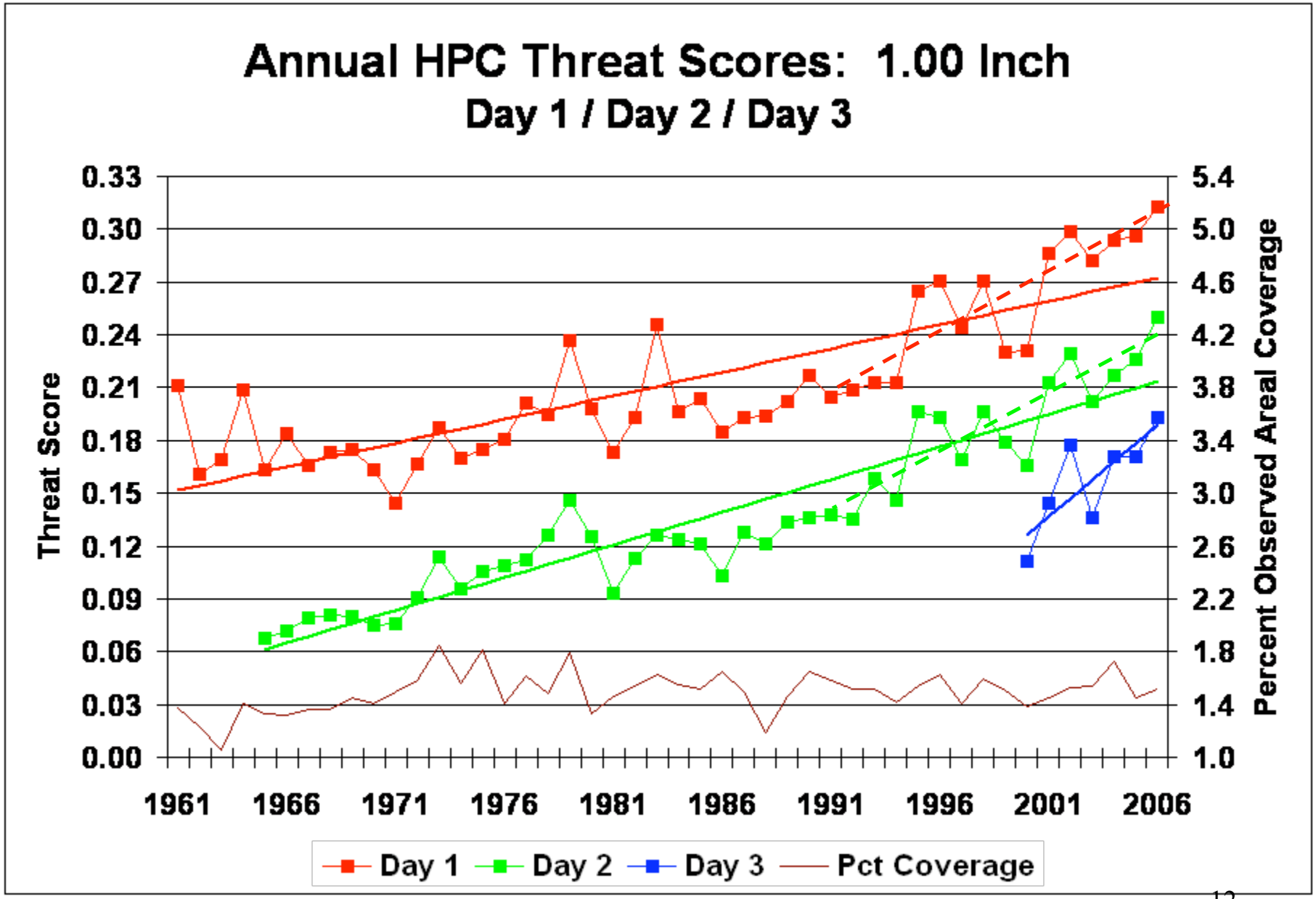

CDAS/Reanl vs GFS
NH/SH 500Hpa day 5
Anomaly Correlation (20-80 N/S)
NH GFS
SH GFS
NH CDAS/Reanl
SH CDAS/Reanl
Anomaly Correlation
90
85
80
75
70
65
60
55
50
45
40
1960
1970
1980
1990
2000
YEAR
NH
Reanl
SH
Reanl
NH
SH
Record
Value
Record
Improvement

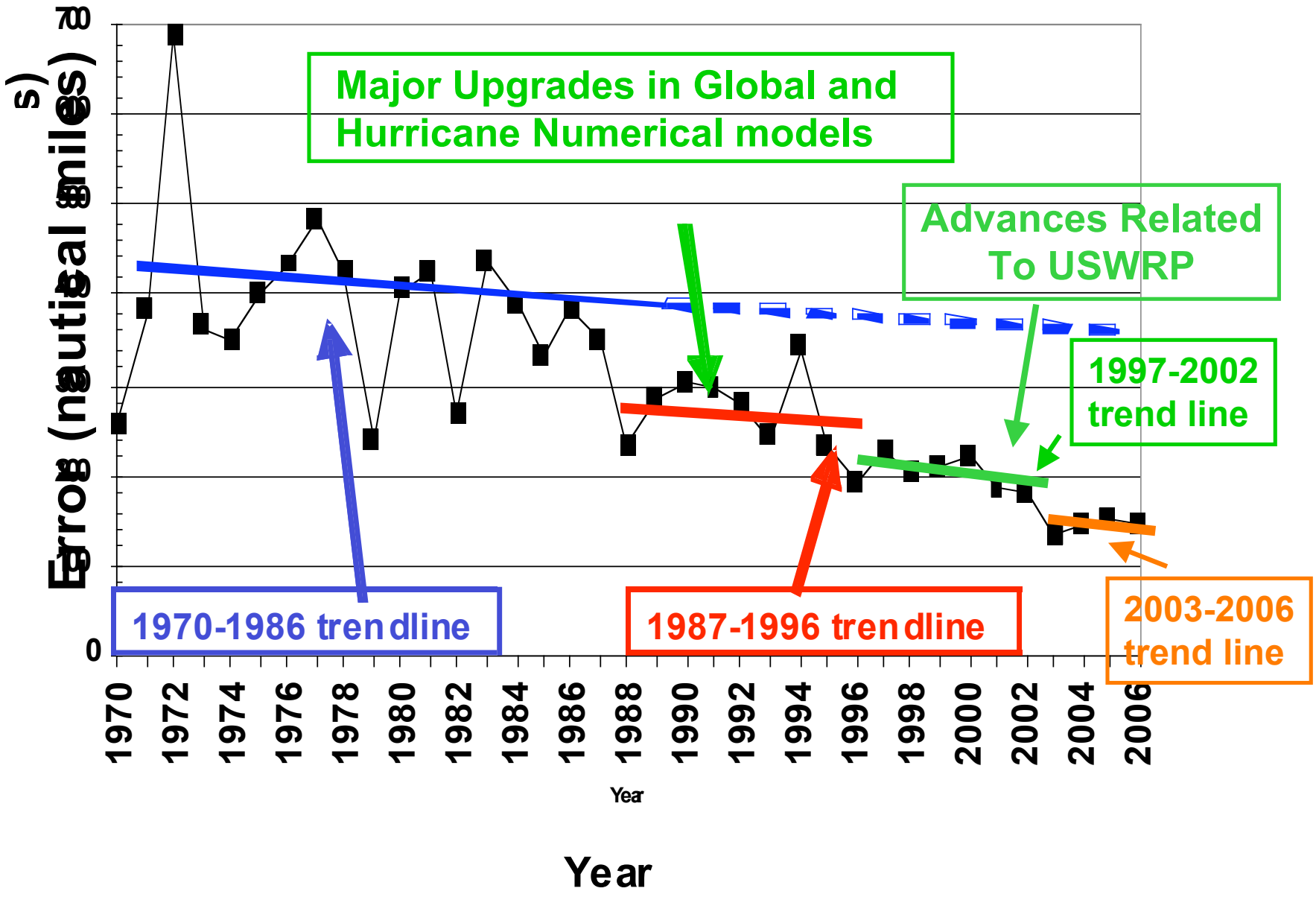
U.S. Seasonal Temperature - Skill

0.5 Month Lead – 4 Year Running Average vs. GPRA Goal

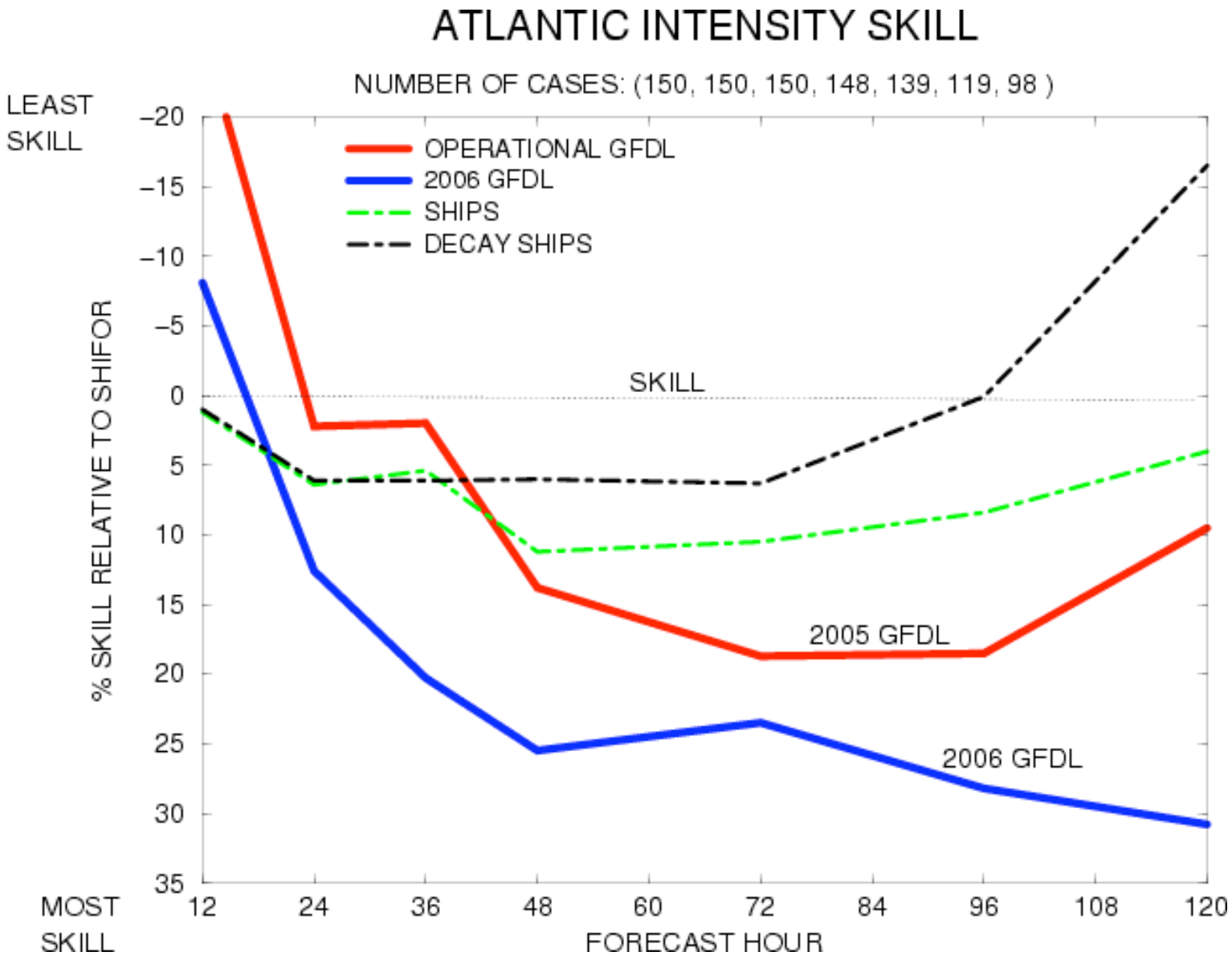


- Climate Forecast System: First dynamic operational climate forecast model implemented August 2004
- Climate Test Bed established in 2005, focused on improving the Climate Forecast System and related seasonal forecast products


Annual HPC Threat Scores: 1.00 Inch
Day 1 / Day 2 / Day 3
Threat Score
0.33
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00
Percent Observed Areal Coverage
5.4
5.0
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
1961
1966
1971
1976
1981
1986
1991
1996
2001
2006
Day 1
Day 2
Day 3
Pct Coverage


NHC Atlantic 72 hr Track Forecast Errors
Errors (nautical miles)
0
Major Upgrades in Global and Hurricane Numerical models
Advances Related To USWRP
1997-2002 trend line
1970-1986 trendline
1987-1996 trendline
2003-2006 trend line
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year

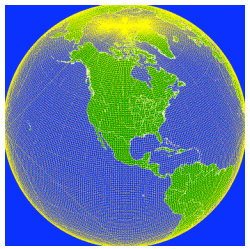
2006 UPGRADES SHOULD PROVIDE SIGNIFCIANTLY BETTER INTENSITY PREDICTION



Model Challenges in the Weather-Climate Linkage

Focus on the Land Model

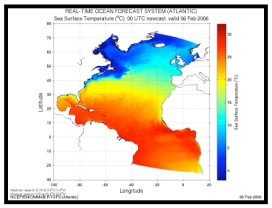
2007 NCEP Production Suite
Atmospheric Model Dependencies



Ensemble
NAEFS

Hurricane/GFDL
Hurricane WRF

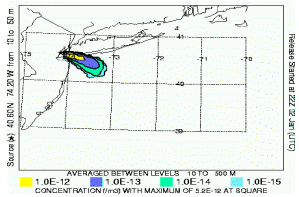
HYCOM
Ocean



Global
GFS

SREF
WRF-NMM
WRF-ARW
ETA
RSM

Dispersion



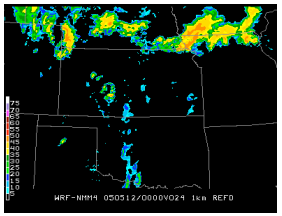
Global
Data
Assimilation

Climate
CFS
MOM3

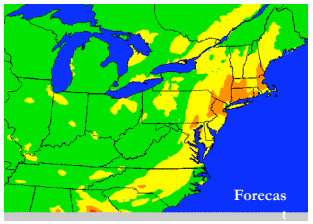
N
D
A
S

Regional
NAM – WRF
NMM

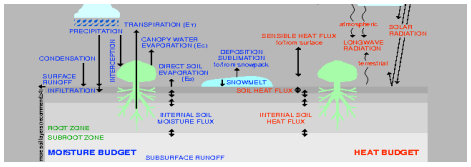
Sev Wx
WRF-NMM
WRF-ARW



Air Quality

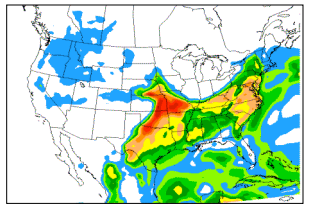


NOAH Land Surface Model



L D A S

Rapid Update Cycle



Summary of Models

Model	CFS Climate	GFS Global/Wx	NAM Regional/Wx	Ensembles
Resolution	T62 (~200km) 64 levels	T382(~32km) to 7.5days T190(~70km) to 16 days 64 levels	12 km 60 levels	**NAEFS-** T126(~105km) 28 levels **SREF-** 32-45km/60 lvls
Forecast length	10 months 2/day	16 days 4/day	84 hrs 4/day	**NAEFS** – 16 days 4/day **SREF** – 87 hrs 4/day
# of Members	60	N/A	N/A	**NAEFS** – 60/day **SREF** – 84/day

NCEP has embraced the weather-climate connection in the strategy for model development.

Over the past 8-10 years, the Environmental Modeling Center (EMC) has adopted the joint development of EMC models for both weather and seasonal climate prediction.

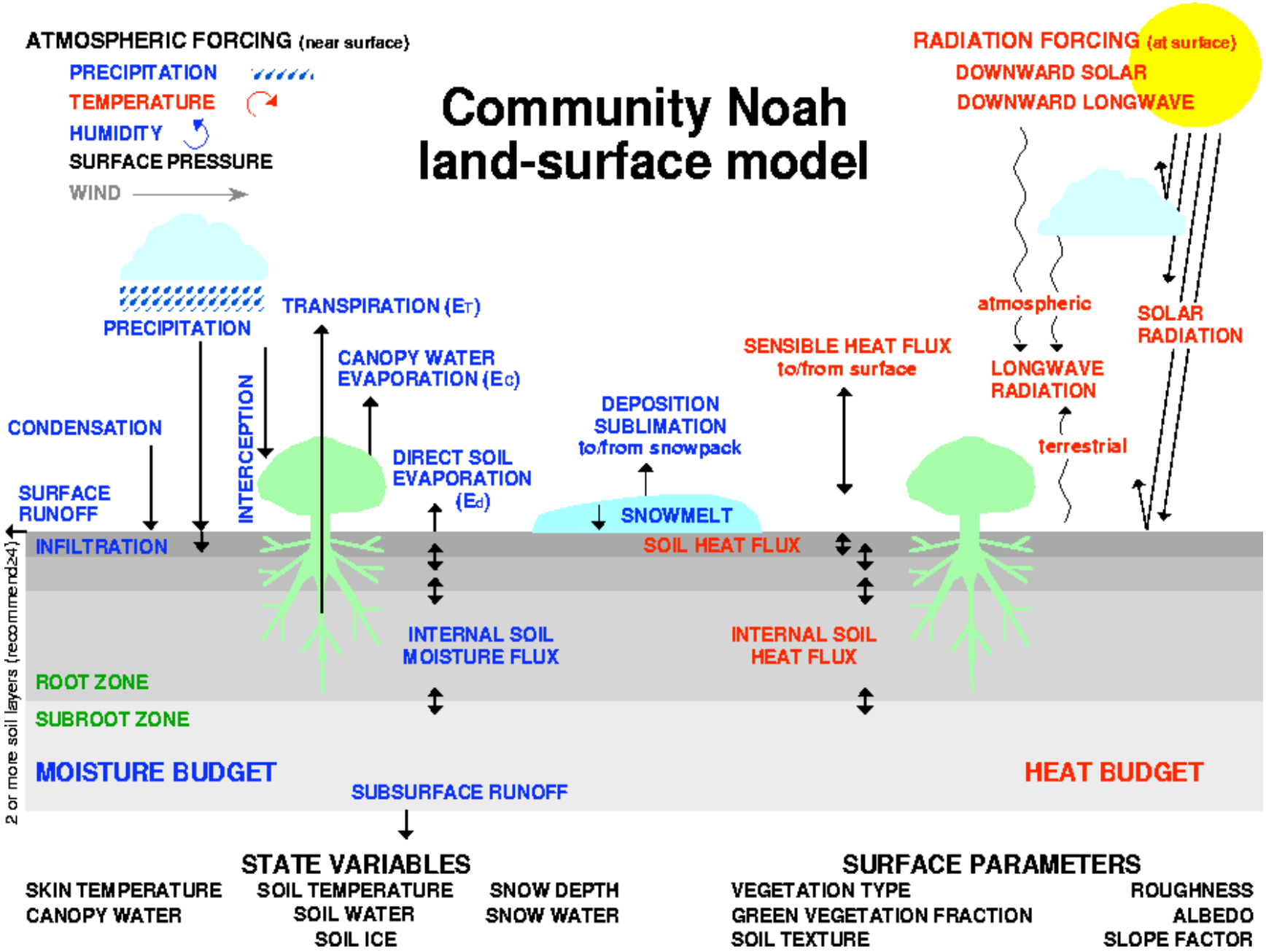
Marine & Coastal Ocean	Mesoscale Atmosphere	Global Climate & Weather Atmosphere & Ocean	Science
X	X	X	**Data Assimilation** Leader: J. Derber
	X	X	**Climate** Leader: H.-L. Pan
X	X	X	**Model** Atmosphere/Ocean/Ice Dynamics Physics
X	X	X	**Land Surface/Hydrology** Leader: K. Mitchell
	X	X	**Ensembles & Probabilistic Guidance** Leader: Zoltan Toth
X	X	X	**Hurricanes** Leader: N. Surgi
X	X	X	**Products** Development Utilization

An example:
Unifying physics across NCEP mesoscale and global models from weather prediction to seasonal climate prediction:

Noah Land Surface Model
(Noah LSM)

The Noah land surface model is the first EMC physical parameterization package to achieve unification across EMC mesoscale and global models and spanning short-range to seasonal range.

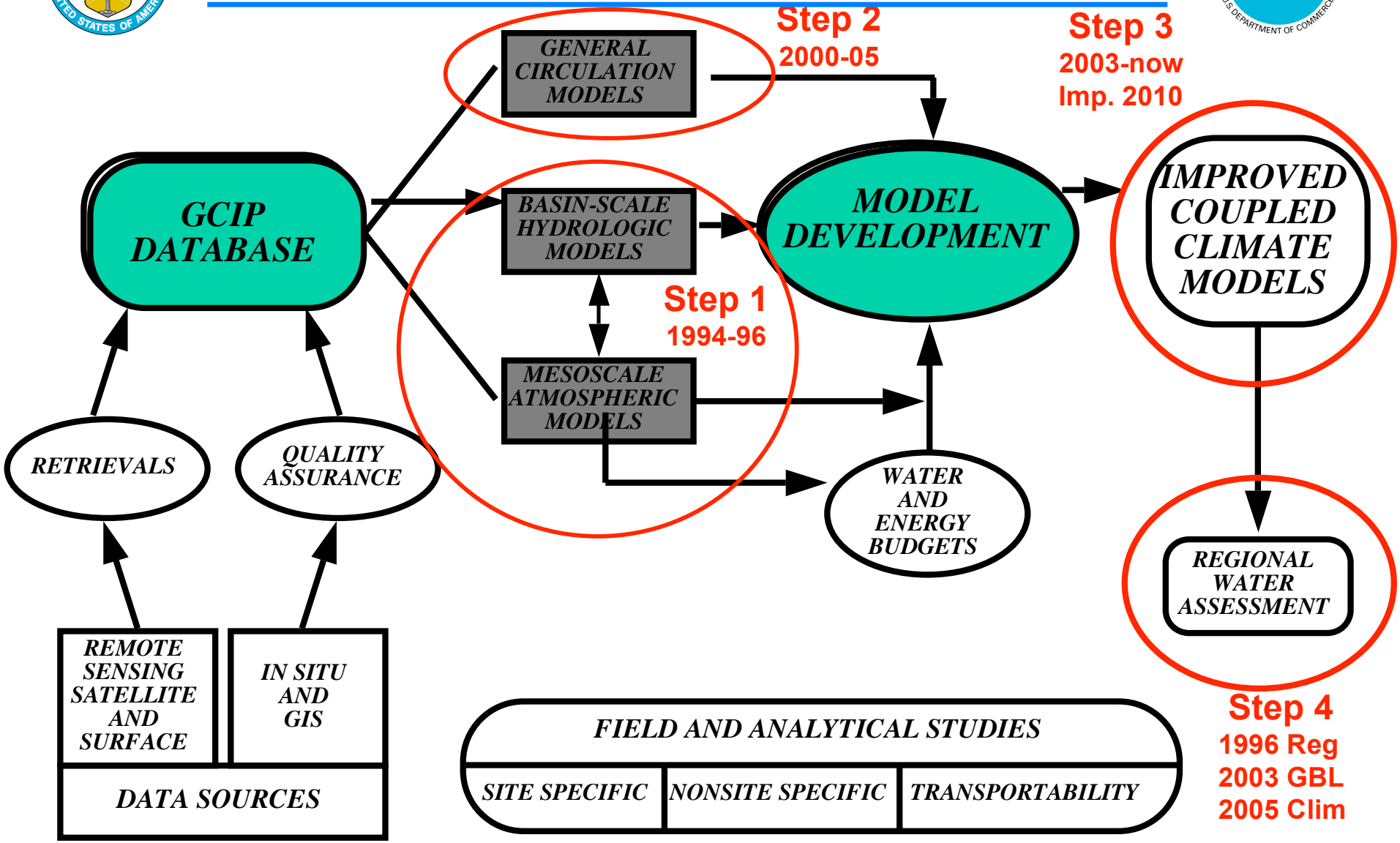
*Supported through the GCIP/GAPP/CPAA Program of the GEWEX (Global Energy and Water Cycle Experiment).


ATMOSPHERIC FORCING (near surface)
PRECIPITATION
TEMPERATURE
HUMIDITY
SURFACE PRESSURE
WIND
Community Noah land-surface model
RADIATION FORCING (at surface)
DOWNWARD SOLAR
DOWNWARD LONGWAVE
PRECIPITATION
TRANSPIRATION (ET)
CANOPY WATER EVAPORATION (EC)
INTERCEPTION
CONDENSATION
SURFACE RUNOFF
DIRECT SOIL EVAPORATION (Ed)
DEPOSITION SUBLIMATION to/from snowpack
SNOWMELT
SENSIBLE HEAT FLUX to/from surface
atmospheric
LONGWAVE RADIATION
terrestrial
SOLAR RADIATION
INFILTRATION
SOIL HEAT FLUX
INTERNAL SOIL MOISTURE FLUX
INTERNAL SOIL HEAT FLUX
ROOT ZONE
SUBROOT ZONE
2 or more soil layers (recommend 4)
MOISTURE BUDGET
HEAT BUDGET
SUBSURFACE RUNOFF
STATE VARIABLES
SKIN TEMPERATURE
SOIL TEMPERATURE
SNOW DEPTH
CANOPY WATER
SOIL WATER
SNOW WATER
SOIL ICE
SURFACE PARAMETERS
VEGETATION TYPE
ROUGHNESS
GREEN VEGETATION FRACTION
ALBEDO
SOIL TEXTURE
SLOPE FACTOR

Features of the NCEP Noah LSM

- Flexible number of soil layers (presently 4)
- Includes Seasonal cycle of vegetation cover
- Treats sub-grid distribution of precipitation/infiltration
- Surface energy and water balance
- Comprehensive snowpack treatment
- Soil freeze/thaw treatment
- Provided as a community model for the research community by NCEP, NCAR and NASA partnership
  - 1D column model test bed for external collaborators
  - 3D test bed for external collaborators
    - Any domain from regional to national to global

Noah Development Strategy

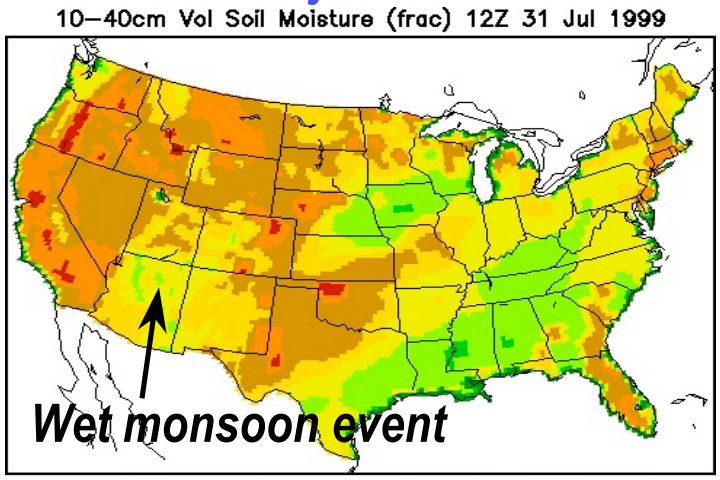


1) Develop/test/assess first on continental-scale basins in mesoscale models, then test in GCMs
2) Promote multi-disciplinary approach between meteorologists, hydrologists & remote sensing

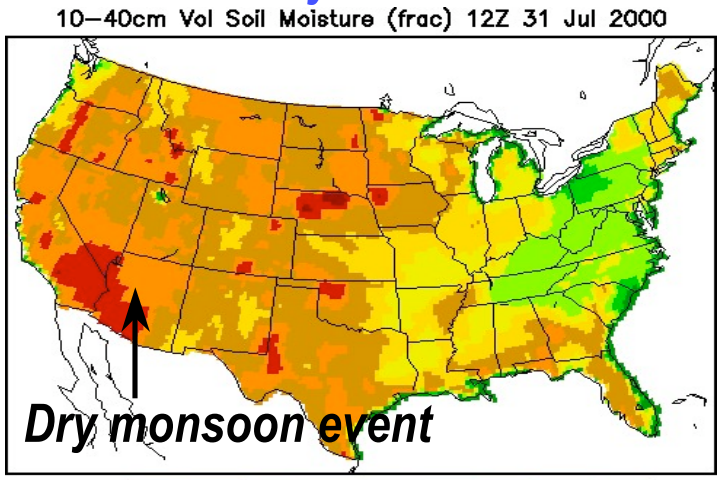
OPS COUPLED LAND-ATMOSPHERE NCEP MESOSCALE MODEL

(Model captures interannual variability of daytime max temperature and model soil moisture)

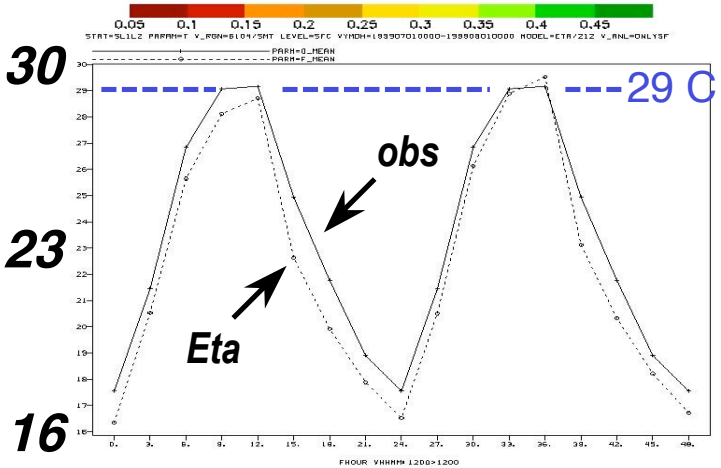
July 1999



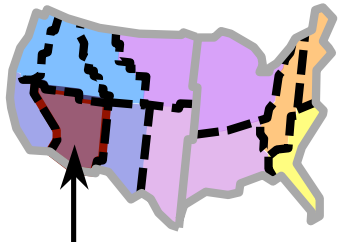
July 2000



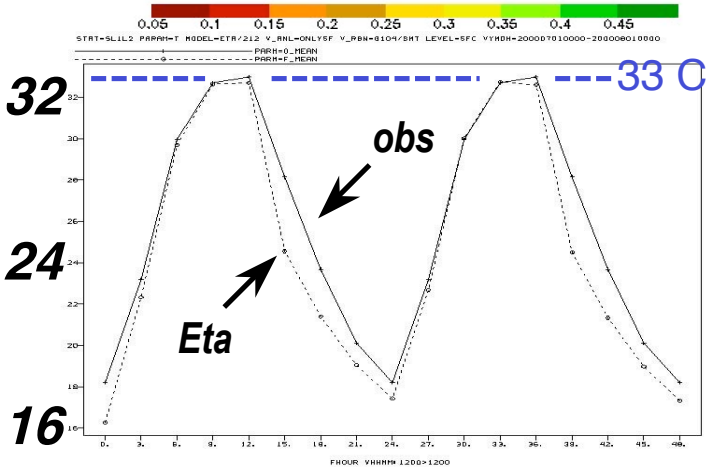
Meso model end-of-month 2nd layer volumetric soil moisture



Meso model monthly-mean 2-m (C) air temperature vs obs: interior Southwest



interior Southwest

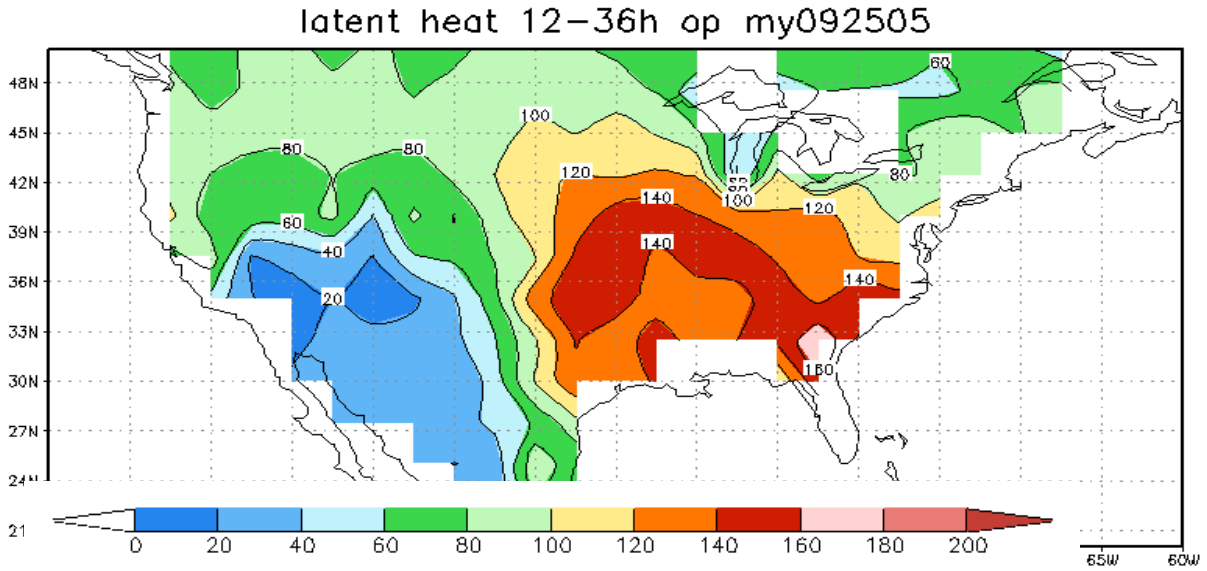


Upper: Eta model layer 2 (10-40 cm) volumetric soil moisture is relatively moist (dry) in July 1999, left (July 2000, right). Lower: Verification of operational Eta model multi-station, monthly-mean 2-m air temperature for interior Southwest: moister and cooler (warmer and drier) conditions in July 1999, left (July 2000, right) are well-captured.

Impact of Noah LSM implementation in GFS: example of warm season forecasts

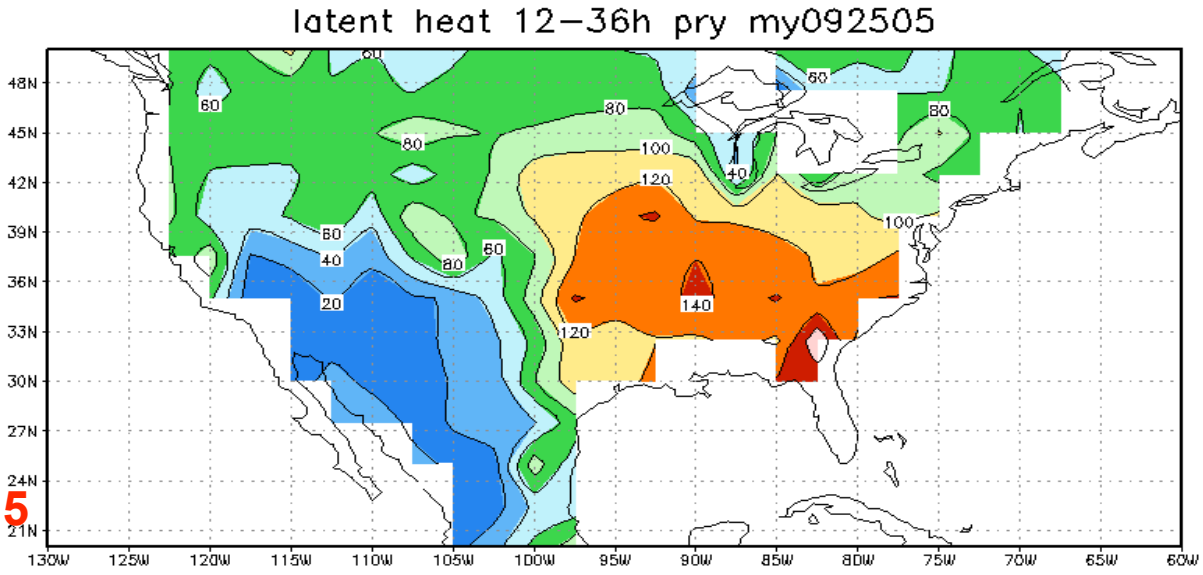
Noah LSM reduced longstanding high bias in GFS surface evaporation (W/m^2) over east half of CONUS

Operational GFS



09-25 May 2005

17-day mean surface Latent heat flux



Parallel GFS test using improved Noah LSM

Noah LSM implemented in NCEP GFS in late May 05

Noah LSM will be implemented in next operational upgrade of CFS

Example of impact of Noah LSM upgrade on CFS southwest U.S. Monsoon Forecasts

Summer:

1999 (wet U.S. monsoon)

vs.

2000 (dry U.S. monsoon)

CFS/Noah/GLDAS

vs.

CFS/OSU/GR2

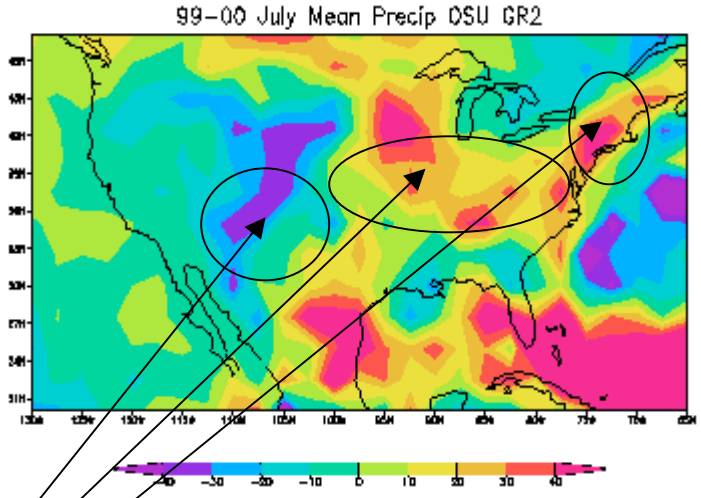
10 CFS members each
(initialized from late June)

Improving CFS prediction skill for summer precipitation over CONUS
Improvements in land surface physics (Noah LSM) and land data assimilation (GLDAS).

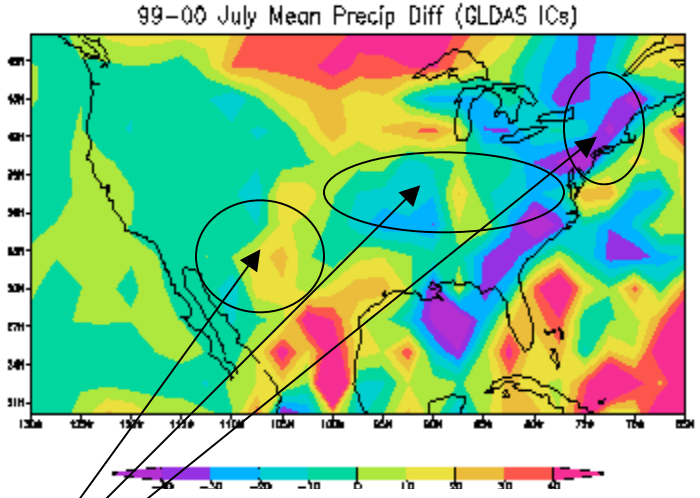
Interannual Precipitation Difference (mm): July1999-minus-July2000

10-member CFS Ensemble Mean Forecast initialized from mid June

T126 CFS / OSU / GR2

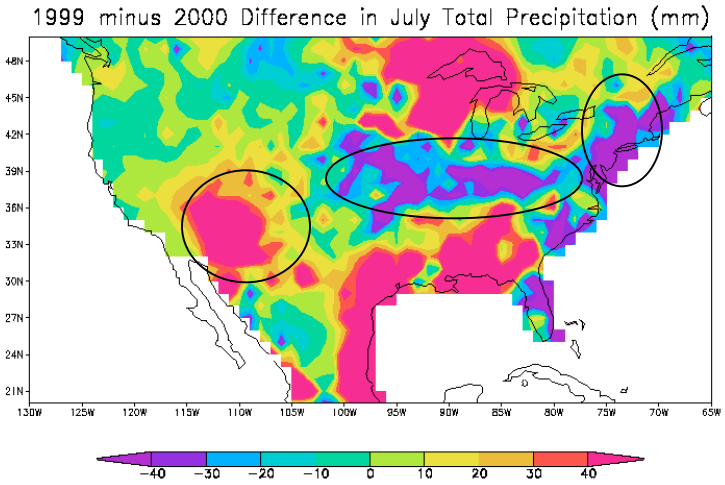


T126 CFS / Noah / GLDAS



Wrong sign of interannual difference

Correct sign of interannual difference



OBSERVED:

(CPC gauge-obs analysis)

July 99 was wet monsoon

July 00 was dry monson

Next Generation CFS

- Coupled atmosphere-ocean-land surface-cryosphere system
  - Improvements to
    - ODA (MOM3 → MOM4)
    - "Unified Physics"
    - Atmospheric model
      - Sigma-pressure hybrid model
      - Upgrades to microphysics, radiation,…
    - Atmospheric data assimilation (GSI)
  - ESMF-based coupling and model structure
- Reanalysis (1979-present)
- Reforecast for
  - Weather & Week2 (1-14 days)
  - Monthly (2 weeks to 2 months)
  - S/I (2-12 months)
- Estimated completion January 2010

Proposed Time Line for CFS "Next"

- April 2007: Implementation of the GSI scheme for GFS.
- Jun 2007: Testing ESMF coupler for GFS and MOM4.
- Aug 2007: Pilot studies for fully coupled reanalysis (GFS, GODAS & GLDAS)

********** **********

- Jan 2008: Production and Evaluation of CFS Reanalysis for 1979 to present
- Jul 2008: Prepare CFS Retrospective Forecasts (2 initial months: October and April)
- Jan 2009: Complete CFS Retrospective Forecasts (remaining 10 months)
- Nov 2009: Compute calibration statistics for CFS daily, monthly and seasonal forecasts.

  Prepare CFS Reanalysis & Retrospective Fcst data for public dissemination.
- Jan 2010: Operational implementation of the next CFS monthly & seasonal forecast suite.

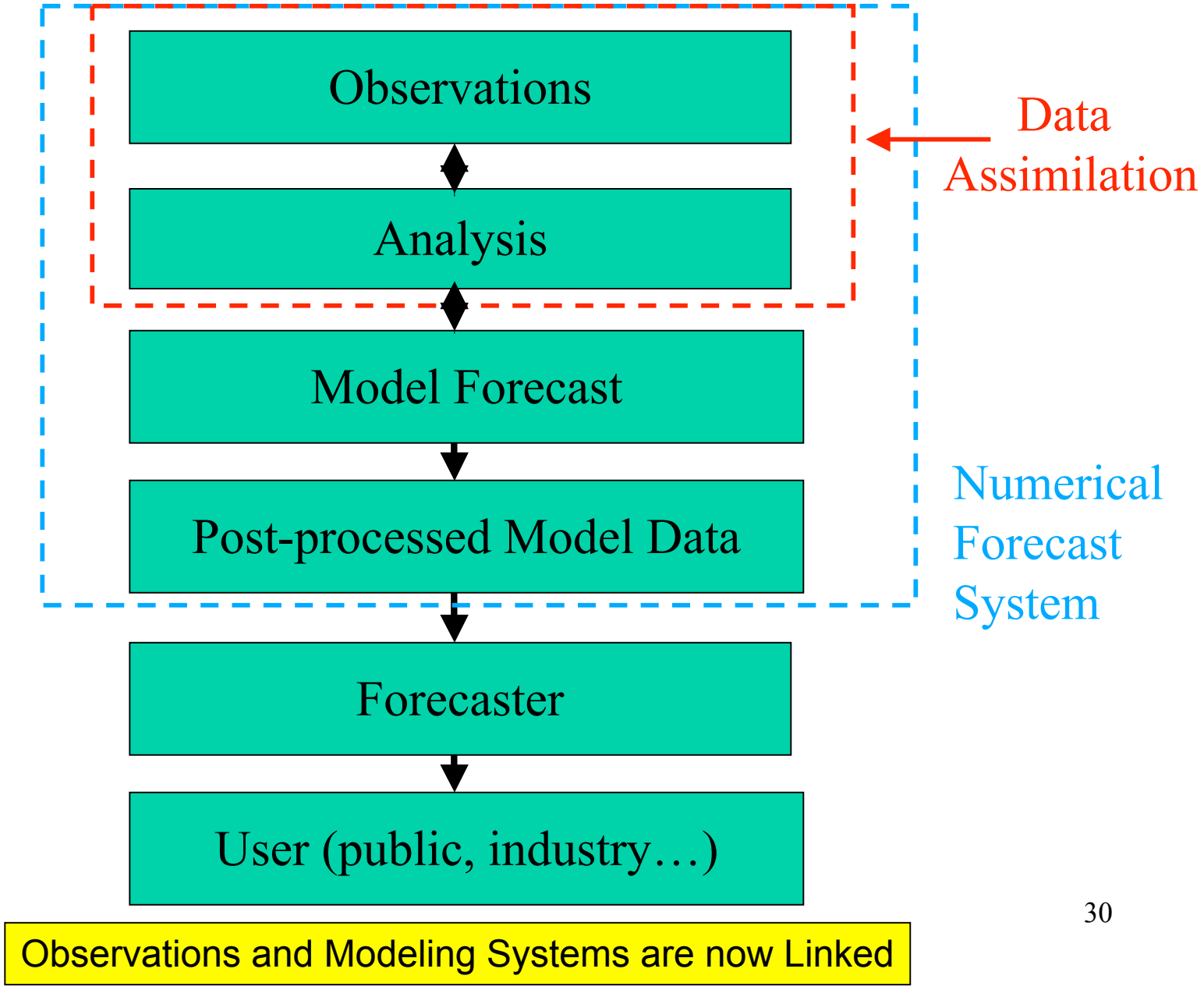
* Reanalysis, reforecast funding for NCEP provided in FY07 Pres. Budget ($800 K);

Funding is critical to move beyond pilot studies

Ongoing Data Assimilation Challenges

The Role of the NASA/NOAA/DoD JCSDA

The Environmental Forecast Process



JCSDA Mission and Vision

- Mission: To accelerate and improve the quantitative use of research and operational satellite data in weather, ocean, climate and environmental analysis and prediction systems
- Vision: A weather, ocean, climate and environmental analysis and prediction community empowered to effectively use increasing amounts of advanced satellite observations

The Joint Center for Satellite Data Assimilation

- Formed in 2001
- Infrastructure for real-time access to operational and research satellite data from GOES, AMSU, Quikscat, AIRS, MODIS, COSMIC, WINDSAT,…
- Community fast forward radiative transfer scheme … operational data assimilation and model forecast systems available to research and forecast communities
- NASA/GFSC and NOAA working on identical data assimilation system
- Supports “internal” and “external research” and data assessments on NOAA/NCEP computers

The Research Community is now using the operational infrastructure.

The Operational Community is now accelerating use of satellite data.

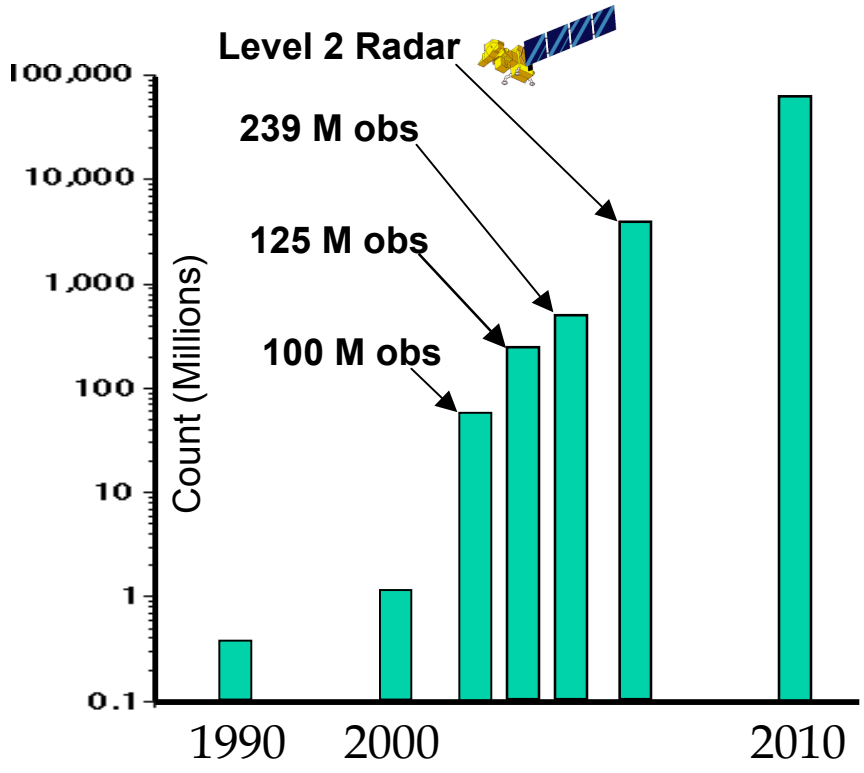
Satellite data used operationally within the NCEP Global Forecast System (2007)

AIRS sounder radiances	**TRMM precipitation rates**
HIRS sounder radiances	**ERS-2 ocean surface wind vectors**
AMSU-A sounder radiances	**Quikscat ocean surface wind vectors**
AMSU-B sounder radiances	**AVHRR SST**
MODIS polar winds	**AVHRR vegetation fraction**
GOES sounder radiances	**AVHRR surface type**
GOES, Meteosat, GMS winds	**Multi-satellite snow cover**
GOES precipitation rate	**Multi-satellite sea ice**
SSM/I ocean surface wind speeds	**SBUV/2 ozone profile and total ozone**
SSM/I precipitation rates	

New in 2007: COSMIC
AIRS "Heavy"

Satellite Data Ingest

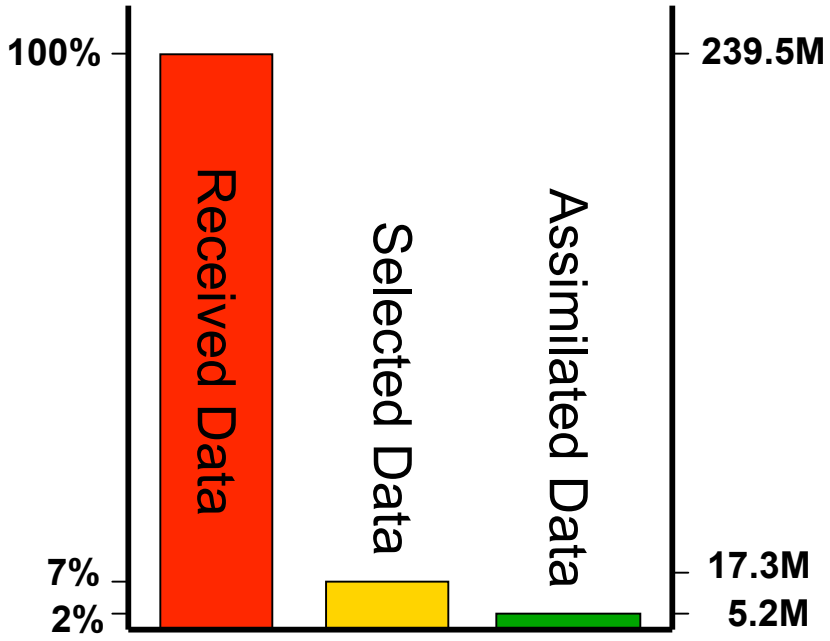
Daily Satellite & Radar Observation Count



Five Order of Magnitude Increases in Satellite Data Over Ten Years (2000-2010)

Daily Percentage of Data Ingested into Models

*2006 Data

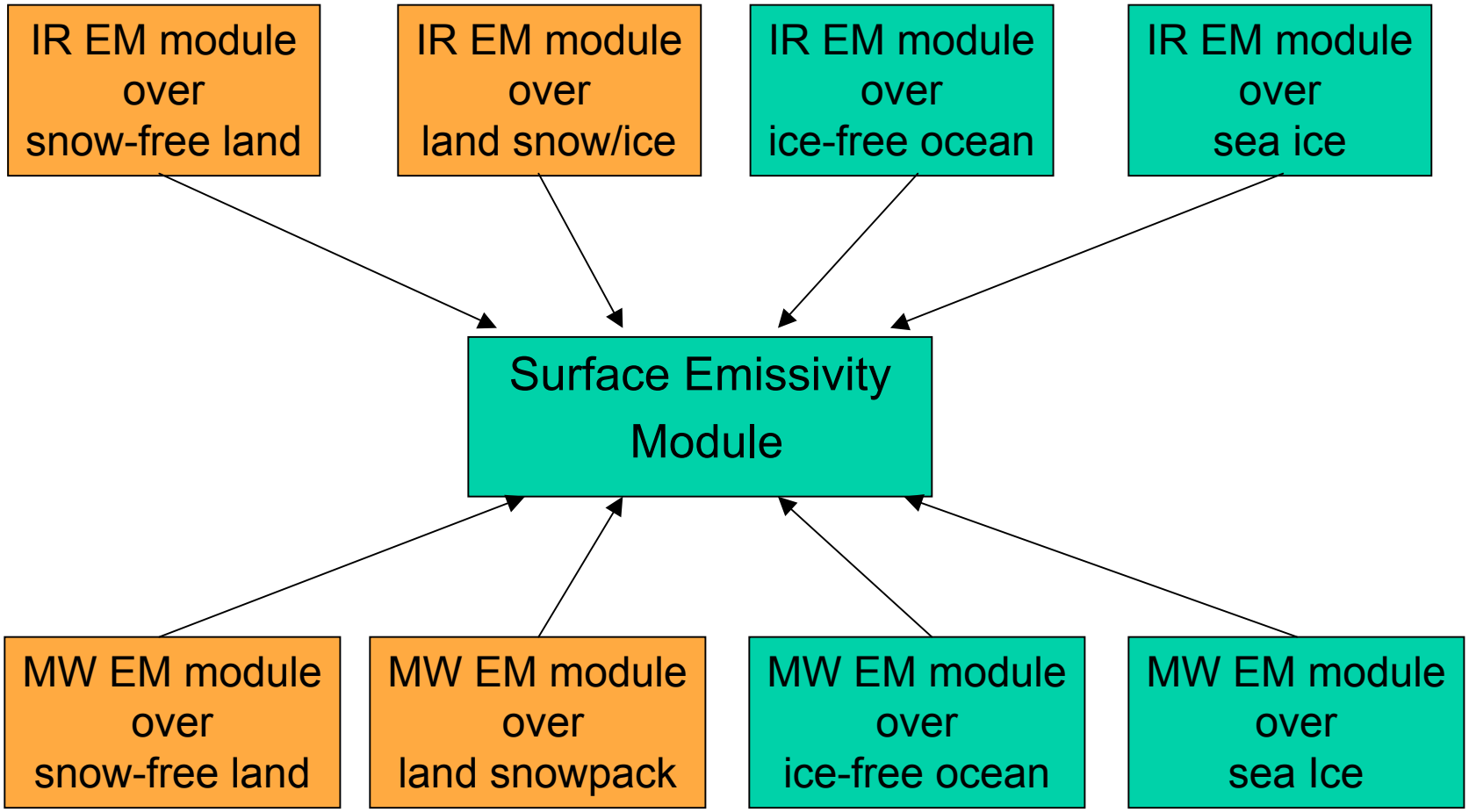


Received = All observations received operationally from providers
Selected = Observations selected as suitable for use (cloud free, …)*
Assimilated = Observations actually assimilated into models

*Science, data resolution, computer issues,… need to be addressed
Top priority Science issue: Surface Emissivity

Surface Emissivity Module (EM) in JCSDA Community Radiative Transfer Model: CRTM

Surface emissivity as function of satellite sensor channel, incidence angle and earth surface conditions

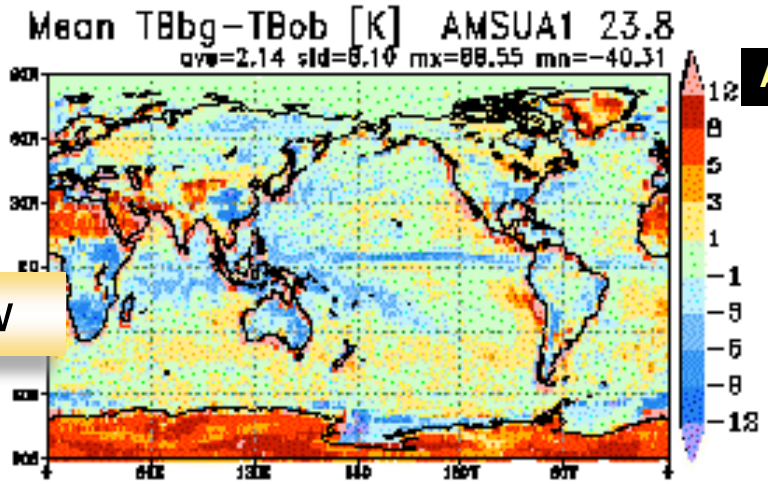


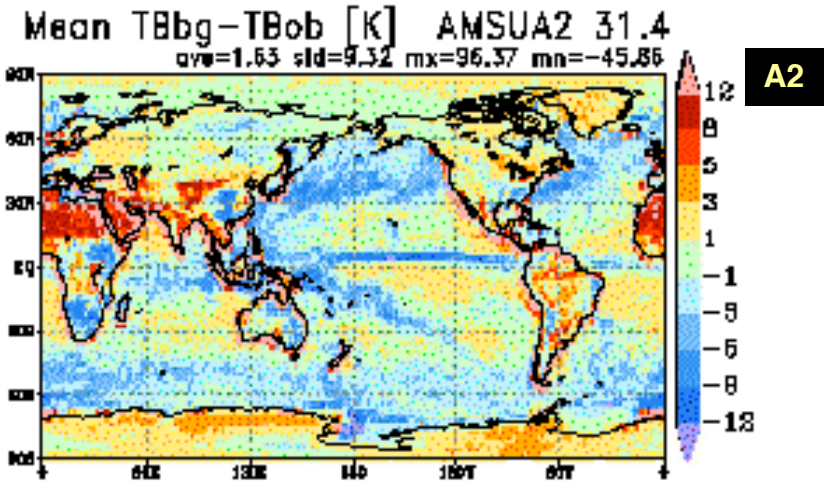
Impact of model simulated land states on atmospheric data assimilation is substantial. Such states include land temperature, snowpack, vegetation cover, soil moisture, soil ice.

Rejection rate of satellite observed radiances over landmass is far greater than over the ocean, pointing to strong need for better modeling and observation of land sfc

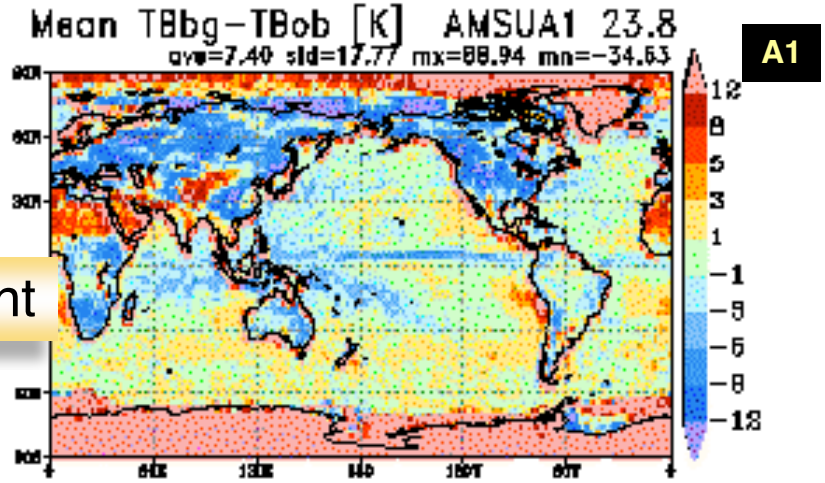
Monthly Mean T_B^{ges}-T_B^{obs}: AMSU-A1&A2 NOAA15

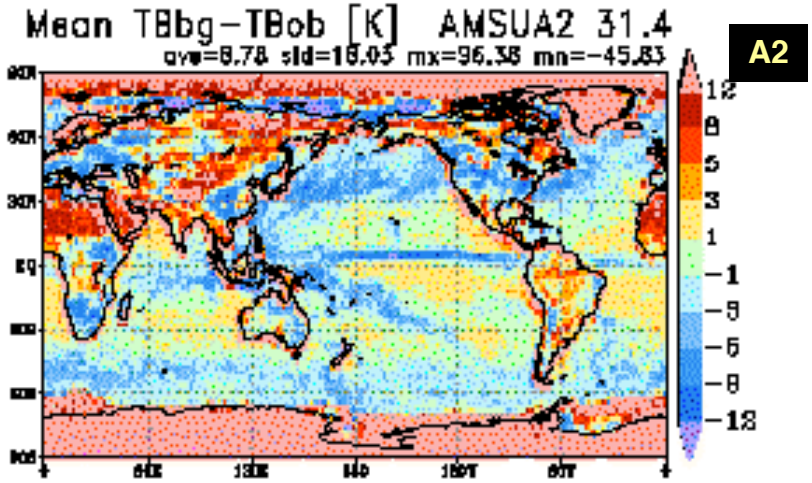
New





current



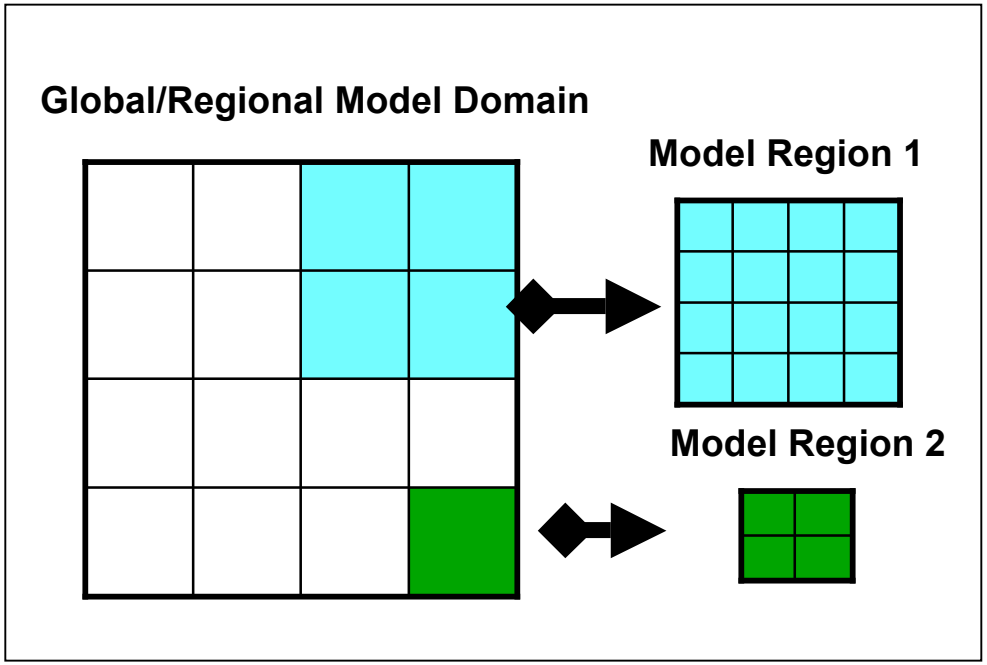


The largest disagreements between observed (obs) and simulated (ges) AMSU satellite radiances occur over the landmass, especially deserts and glacial ice. Recent upgrades have reduced the differences over land, but still large over deserts and glacial.

Future Directions

- Increasing emphasis on ensemble approaches
  - Multi-model ensembles
    - SREF
    - NAEFS
    - Climate Forecast System
- Entering the NPOESS era
  - More rapid access to hyperspectral data
  - GPS soundings
  - Higher resolution surface radiance data
- All models run within ESMF
  - Hybrid
  - Coupled
  - Spanning all scales
  - Models run concurrently
- Operational Earth System model – more explicit hydro applications

ESMF-based System



Summary

- NCEP is positioned to address the climate/weather/water linkage
  - For operational services
  - As a “R2O”/”O2R” transition agent
- Performance metrics continue to improve
  - Based on “earth system” approach to model development and applications
  - Unified climate/weather/water approach

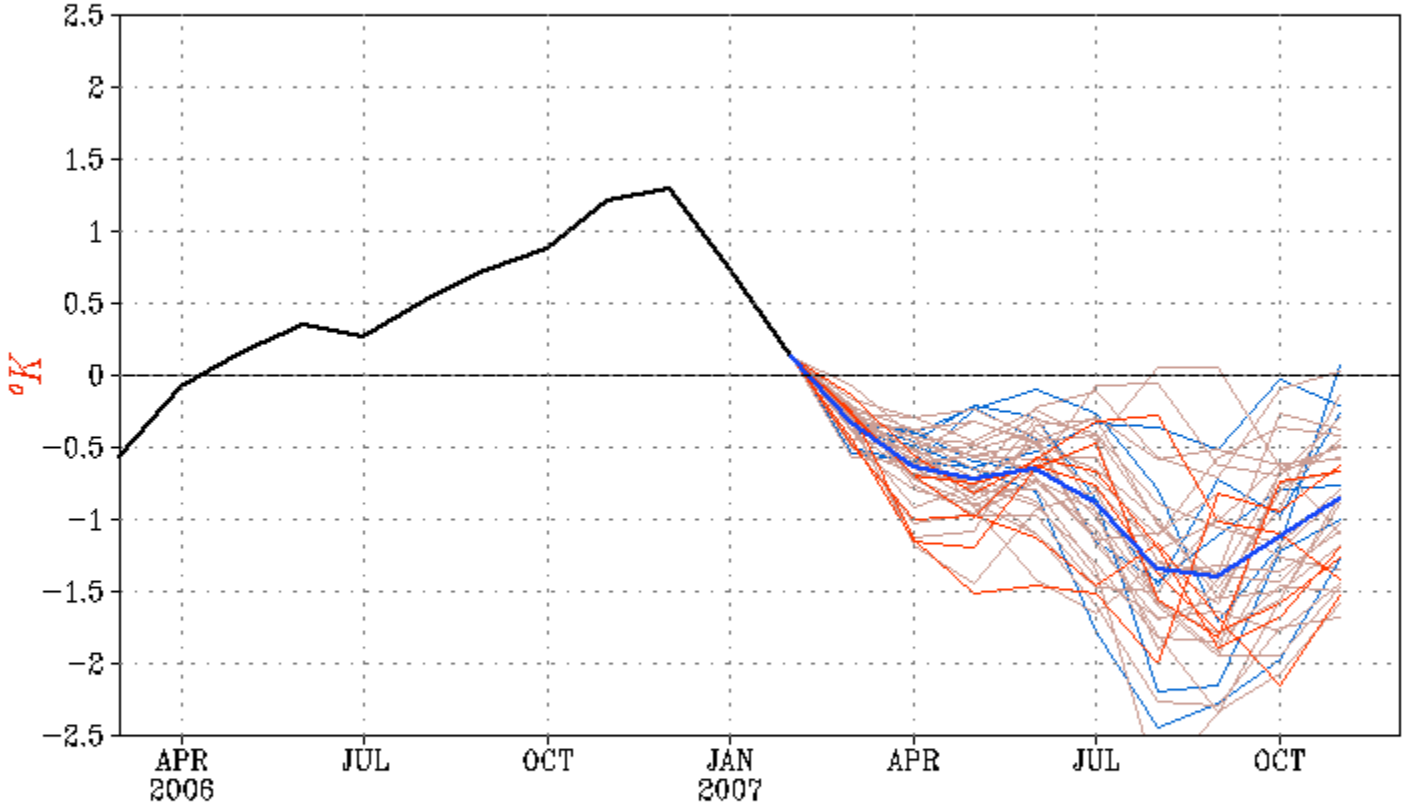
Issues

- Increase use of satellite data, especially over land
- Application of this “operational” model infrastructure for transition and research purposes – ESMF is the critical link
- Obtain resources for reanalysis and reforecast
- Expanding prediction beyond classic climate weather water regimes into ecosystems, coastal zones and air/water quality

NWS/NCEP

Last update: Mon Mar 5 2007
Initial conditions: 6Feb2007–25Feb2007

Forecast *Nino3.4* SST anomalies from CFS



Latest 6 forecast members
Earliest 6 forecast members
Other forecast members
Forecast ensemble mean
OIv2 observation

Forecast initial conditions: 6Feb2007 to 25Feb2007.

Base period for climatology is 1971–2000. Base period for bias correction is 1982–2003.